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## SOIL MOISTURE AND SOIL STRENGTH CHARACTERISTICS OF FIVE HAWAIIAN SOILS

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## INTRODUCTION

What happens when some Hawaiian forest soils are subjected to traffic by vehicles? Do different kinds of forest vegetation use more water than others?

A study of soil moisture and soil strength characteristics of several Hawaiian soils has thrown some light on these questions. It is being conducted jointly by the Pacific Southwest Forest and Range Experiment Station of the U.S. Forest Service and the Army Mobility Research Center of the U.S. Army Engineers in cooperation with the State of Hawaii, Department of Agriculture and Conservation, and the Hawaiian Sugar Planters Association. This progress report discusses the results of observations at four locations—three on Oahu and one on the Big Island.

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## METHODS

The four locations contain five soil series, and are located at Upper Nuuanu Valley, Wahiawa, and Helemano on Oahu and at Honomu, near Akaka Falls on the island of Hawaii (table 1).

Soil moisture and soil temperature measurements are taken daily with a Colman ohmmeter and Colman fiberglas soil moisture units [1] buried at 1 1/2, 4 1/2, 7 1/2, and 10 1/2 inch depths in the center of each site. Since water tables near the ground surface can influence soil moisture in the surface foot, groundwater fluctuations are measured from wells 4 feet deep or to the depth of the hardpan when present. [2] Rainfall measurements are taken from standard (non-recording) rain gages, so that soil moisture accretion and depletion rates can be related to precipitation.

Soil strength measurements are taken periodically at each site. Soil strength is the resistance of a soil to an applied stress, and is measured with a cone penetrometer which measures resistance to pressure. Penetrometer readings at specified depths as the cone is pressed through the soil (or in a soil sample core) give an index. This index is called the "cone index." [3]

The cone penetrometer is also used to obtain a measure of the effect of traffic on the soil. A sample core of soil is subjected to a standard pounding—the "100-blow remolding test" which provides a remolding index. The cone index is multiplied by the remolding index to provide an expression of the soil's ultimate ability to withstand traffic. This index is called the "rating cone index." [3]

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1/ Colman, E. A. Manual of instruction for use of the fiberglas soil moisture instrument. Calif. Forest and Range Expt. Sta., 1947 (revised 1948, 1950, 1952).

2/ U.S. Army Engineers Waterways Experiment Station, Corps of Engineers. Forecasting trafficability of soils, prediction sites at Vicksburg, Mississippi. Vol. 2, Tech. Memo. 3-331, Report No. 3, Vicksburg, Mississippi. October 1954.

3/ U.S. Army Engineers Waterways Experiment Station, Corps of Engineers. Trafficability of soils, a summary of trafficability studies through 1955, by S. J. Knight. Tech. Memo 3-240, 14th Sup., Vicksburg, Mississippi. December 1956.

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Table 1. —Soil-strength sites and soil characteristics

| Item | Nuuanu Valley | | Wahiawa | | Helemano | | Honomu | |
|---|---|---|---|---|---|---|---|---|
| | Lolekaa series | | Wahiawa series | | Manana | Paaloa series | Akaka series | |
| | Bamboo | Swamp-mahogany eucalyptus | Pineapple | Eucalyptus | Grass | Ohia, koa, false staghorn fern | Cane and grass | Swamp-mahogany eucalyptus |
| Elevation, feet | 1,150 | 1,100 | 840 | 840 | 1,280 | 1,240 | 2,050 | 2,100 |
| Annual rainfall, inches | 90 | 90 | 50 | 50 | 70 | 70 | 250 | 250 |
| Topography | slope (27%) | slope (18%) | level plateau | level plateau | ridgetop (4%) | slope (40%) | slope (12%) | slope (12%) |
| Bulk density, gms/cc, 6-12 in. depth | .81 | .73 | 1.16 | 1.00 | 1.20 | 1.18 | .40 | .28 |
| Cone index, 1/ 6-12 in. depth | 199 | 125 | 153 | 203 | 153 | 169 | 59 | 63 |
| Remolding index, 1/ 6-12 in. depth | .90 | 2/ 1.3 | 1.7 | .55 | .43 | .77 | .70 | .70 |
| Rating cone index, 1/ 6-12 in. depth | 179 | 162 | 260 | 112 | 66 | 130 | 41 | 44 |
| Field soil moisture 3/ content, 6-12 in. depth, | | | | | | | | |
| percent by weight | 57.8 | 87.2 | 37.1 | 42.8 | 51.0 | 37.9 | 354.9 | 365.0 |
| inches of water | 2.81 | 3.82 | 2.58 | 2.57 | 3.67 | 2.68 | 8.52 | 6.13 |
| Soil moisture content, .06 atm. tension, 6-12 in. depth, | | | | | | | | |
| percent by weight | 62.4 | 87.7 | 39.7 | 48.1 | 40.5 | 42.2 | 228.6 | 297.6 |
| inches of water | 3.03 | 3.84 | 2.76 | 2.89 | 2.92 | 2.99 | 5.49 | 5.00 |
| Soil moisture content, 6-12 in. depth saturation, | | | | | | | | |
| percent by weight | 92.4 | 102.2 | 51.2 | 64.8 | 50.4 | 52.2 | (4/) | (4/) |
| inches of water | 4.49 | 4.48 | 3.56 | 3.89 | 3.63 | 3.70 | -- | -- |

1/ Values derived from measurements taken from a single wet day.
2/ Stony soil-value derived from only one sample.
3/ Soil moisture sampled concurrent to strength test.
4/ No values derived; portions of soil core dried irreversibly in the saturation pan.

## SOIL MOISTURE CHARACTERISTICS

In general, the five soils drain rapidly, and moisture depletion rates appear to be very rapid during dry spells. Differences in soil moisture depletion associated with differences in vegetation are apparent, especially during dry spells. Infiltration and percolation were moderately high for all sites.

Daily observations showed that 1/10 inch of rainfall is the minimum storm size capable of wetting the soil in the 0 to 3 inch layer. The surface soils are generally well drained, as indicated by the difference in moisture content from saturation to moisture retained at .06 atmosphere tension (table 1). The soils are compactible with the possible exception of Akaka soils. The effect of this compaction on infiltration and percolation is not known.

The soils feel like silty clay or silty clay loam in the field but are clay in texture when analyzed. They are sticky and very slippery when wet.

Lolekaa soils (Nuuanu Valley). —During a wet period, the rate at which Lolekaa soils absorbed moisture was similar at both the bamboo site and the eucalyptus site, but the depletion rates during a dry period differed greatly. The soil under the bamboo dried about twice as fast as the soil under eucalyptus (fig. 1). Differences in evapotranspiration losses, ventilation, understory vegetation, and slight terrain differences may be contributing factors.

Wahiawa soils. —When a eucalyptus site and an adjacent pineapple field at Wahiawa were compared, we found that the soil under the eucalyptus dried faster and remained drier for a longer period than that under pineapple (fig. 2). Pineapple has a limited root system and is not a heavy user of water.

Paaloa and Manana soils. —At Helemano, soil moisture gains and losses were compared between soils under an open grass site and adjacent soils under a mixed forest of ohia and koa with an undergrowth of false staghorn fern. The forest-covered Paaloa soils maintained fairly uniform soil moisture content, but the grass-covered Manana soils showed a constant fluctuation in soil moisture because of rapid evaporation losses after rain (fig. 3). However, during the drier summer months the grass-covered soils are highly receptive to rainfall owing to their high infiltration and percolation rates.

Akaka soils. —These soils are subjected to heavy, frequent rainfall. They remain wet throughout the year under cane and grass and the adjoining eucalyptus forest. Although they drain rapidly between rains, they never become dry (fig. 4). An observation well showed that the water table receded from the ground surface to a depth below 4 feet within 24 hours. Soil moisture was sampled to nearly 400 percent by dry weight. This means that 1 pound of this soil can hold 4

Figure 1. --Rainfall and corrected soil moisture unit readings under stands of Eucalyptus robusta and bamboo, 9-12 inch depth, Nuuanu Valley, Oahu.

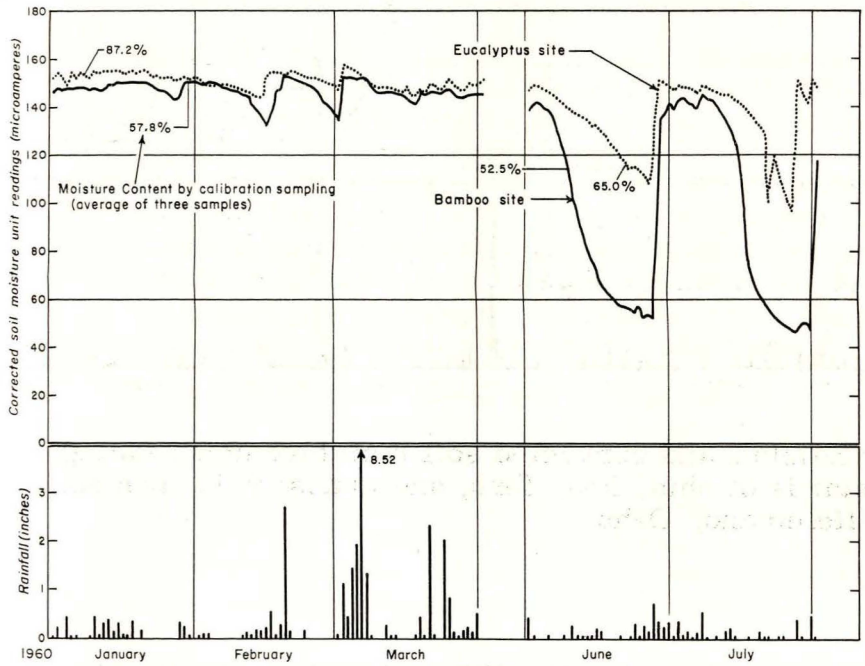
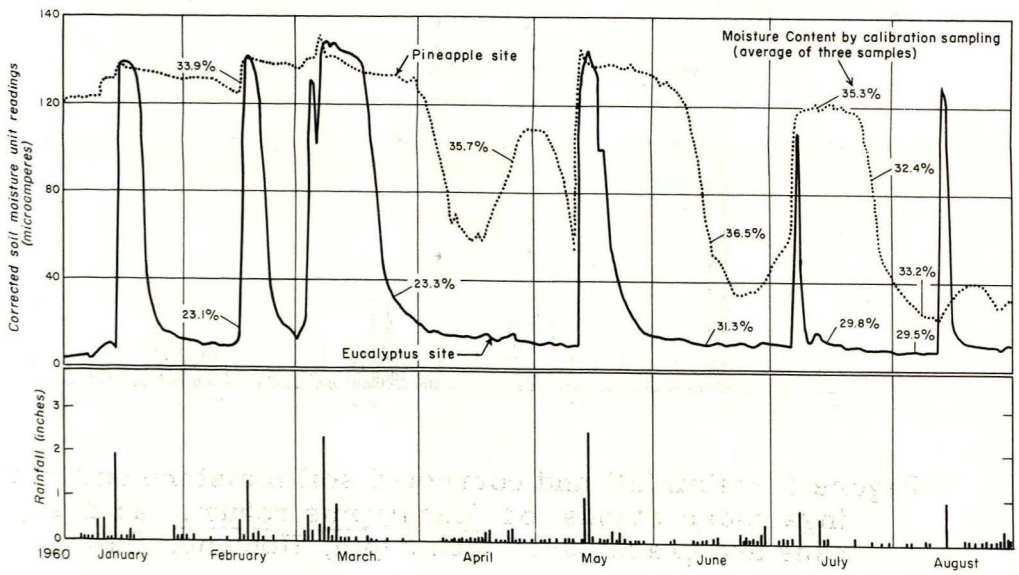



Figure 2. --Rainfall and corrected soil moisture unit readings under stands of eucalyptus and pineapple, 9-12 inch depth, Wahiawa, Oahu.



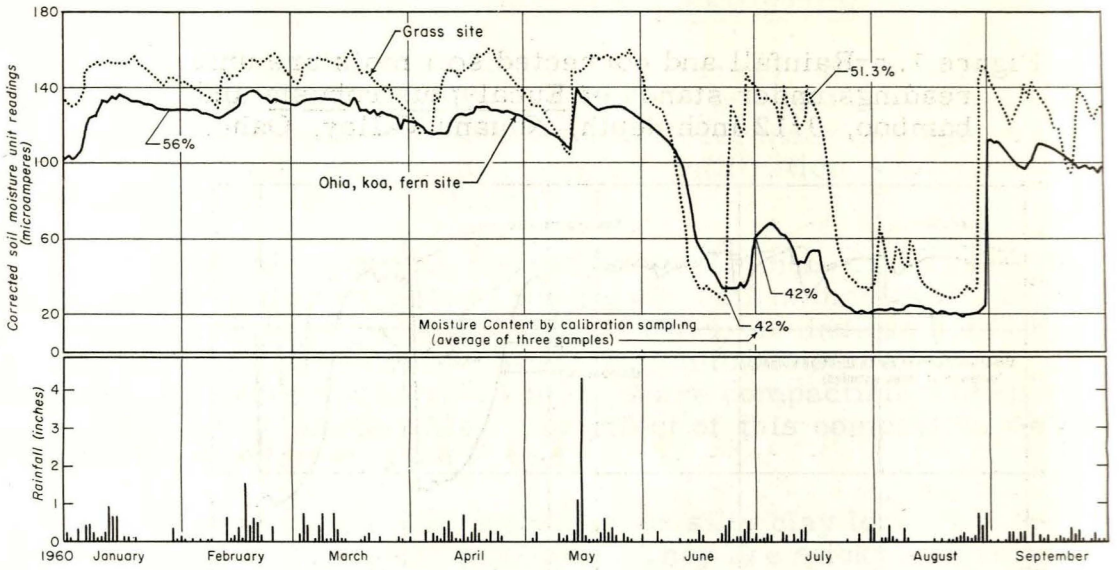



Figure 3.--Rainfall and corrected soil moisture unit readings under stands of ohia, koa, fern, and grass; 9-12 inch soil depth, Helemano, Oahu.

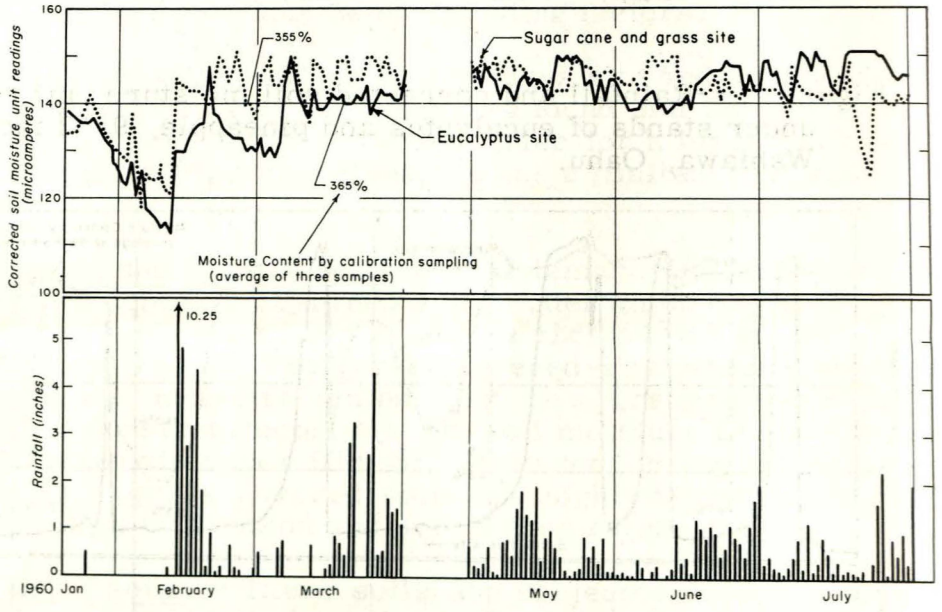



Figure 4.--Rainfall and corrected soil moisture unit readings under stands of Eucalyptus robusta and sugar cane and grass, 9-12 inch depth, Honomu, Hawaii.

pounds of water. Although the Akaka soil is in a gel state, it is rather firm for walking. This soil dries irreversibly (cannot be wet again); the effects of logging or excessive disturbance which may change its characteristics, have not been studied.

## SOIL STRENGTH CHARACTERISTICS

Studies elsewhere in the world[4/] demonstrate that the strength of soils and their reaction to traffic is related to soil moisture content and to the nature, arrangement, and size distribution of inorganic and organic particles. Trafficability is affected primarily by changes in soil moisture content. Therefore, if the water content of a soil can be predicted, its trafficability can be estimated from known or estimated relationships between soil moisture and strength. The trafficability of a given soil can be considered adequate if the soil has sufficient bearing capacity or strength to support a vehicle and sufficient traction capacity to develop the necessary forward thrust.[5/]

The values of cone index, remolding index, rating cone index, and the concurrent field moisture contents listed in table 1 were obtained from measurements taken on a single wet day.

The 6-12 inch layer in the surface foot of a soil is considered the critical layer for strength characteristics. The range of cone indexes of primary importance to trafficability in this layer lies between 30 and 200. Only the most mobile of military vehicles, such as the M29 Weasel (an amphibious, tracked vehicle), can travel on soils with a cone index as low as 30. Only a few military vehicles require cone indexes of over 200.[6/]

The ultimate soil strength of a given area must be rated by its rating cone index at a given soil moisture content. Soil strength requirements for military vehicles (vehicle cone index)[7/] have been determined by the Army Engineers. For example:

| | |
|---|---|
| Truck, 1/4 ton, 4x4, command reconnaissance (Willys Jeep) | 65 |
| Truck, 2 1/2 ton, 6x6, M135 | 62 |
| Truck, 7 1/2 ton, 6x6, prime mover | 65 |
| Bus, 29-passenger, converted type | 112 |
| Tractor, earth moving crawler diesel engine-driven, 61-90 DBHP | 40 |

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4/ U.S. Army Engineers Waterways Experiment Station, Corps of Engineers. Forecasting trafficability of soils, information for predicting moisture in the surface foot of various soils, by C. A. Carlson and J. S. Horton. Tech. Memo 3-331. Report No. 4. Vicksburg, Mississippi. February 1957.

5/ Ibid. (See footnote 3, page 2.)

6/ Ibid. (See footnote 3, page 2.)

7/ The minimum cone index that will permit a vehicle to complete 50 passes.

## STRENGTH CHARACTERISTICS OF THE FIVE HAWAIIAN SOILS STUDIED

The Manana soils at the Helemano grass site and the Akaka soils at the Honomu sites were the weakest of the soils studied. Their rating cone indexes were obtained when the soils were wet, and they probably represent the weakest condition. The Akaka soils had extremely high moisture contents and would definitely remold, that is, their strength characteristics are definitely changed after the 100 hammer blows. Their low remolding index (based on 72 remolding samples) averaged about .40, or a loss in strength of 60 percent.

The rating cone indexes of 41 and 44, measured on the Akaka soils when wet, show that no wheeled vehicles could propel themselves on these sites. Only tracked vehicles can traverse a soil of such low strength. A Jeep would not be able to travel over the Akaka soils but would easily go over the Manana soils at the Helemano grass site. The soils of the Nuuanu, Wahiawa, and the Helemano forest sites are very strong, even when wet, and will support most all wheel-drive vehicles. The Lolekaa and the Wahiawa (pineapple) soils had high remolding indexes: 1.3 and 1.7. These indexes show that under traffic the soils had gained in strength by 30 and 70 percent respectively.